



JUPITER OXYGEN CORPORATION

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**OXY-FUEL BURNER AND INTEGRATED POLLUTANT REMOVAL
RESEARCH AND DEVELOPMENT TEST FACILITY**

**Jupiter Oxygen Corporation
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JUPITER OXYGEN ENERGY TECHNOLOGY

- Development and Application of Oxy-fuel Technology
- Patents and Licensing
- Consulting Service

Fossil Fuel: coal, natural gas, oil, and biomass



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Project Funding

Project revision	Start date	Government cost share	Recipient cost share	Total estimate
0	10/1/2006	\$ 2,051,670	\$ 517,455	\$ 2,569,125
1	4/1/2008	\$ 972,674	\$ 243,162	\$ 1,215,836
2	4/1/2009	\$ 669,784	\$ 173,492	\$ 843,276
2010-11	4/1/2010	\$ 2,825,387	\$ 705,560	\$ 3,530,947
Project total	Completion date 9/30/2011	\$ 6,519,515	\$ 1,639,669	\$ 8,159,184
		79.9%	20.1%	100%



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Project Participants

- Jupiter Oxygen Corporation
- NETL
- Industry and academic partners

SNC Lavalin America, Inc
Reaction Engineering International

Purdue University
Coalteck
Professor Stamps, Evansville University
EPRI



Project Objectives

- Design, construct, and operate a 5 MWe equivalent test boiler facility
- Design, construct, and operate a 20 KWe equivalent IPR[®] facility
- Operate the test facility at steady-state optimum oxy-coal combustion and perform parametric studies
- Demonstrate oxy-coal combustion NO_x levels no higher than 0.15 LB/MMBTU
- Demonstrate that CO₂ from the boiler/ IPR[®] meets the specifications for deep saline aquifer sequestration and/or enhanced oil recovery
- Evaluate the retrofit impact of oxy-coal combustion and the IPR[®] process on power plant design issues
- Generate the necessary technical data required to demonstrate the technologies are viable for technical and economic scale-up and conform to DOE's Carbon Sequestration Program goals

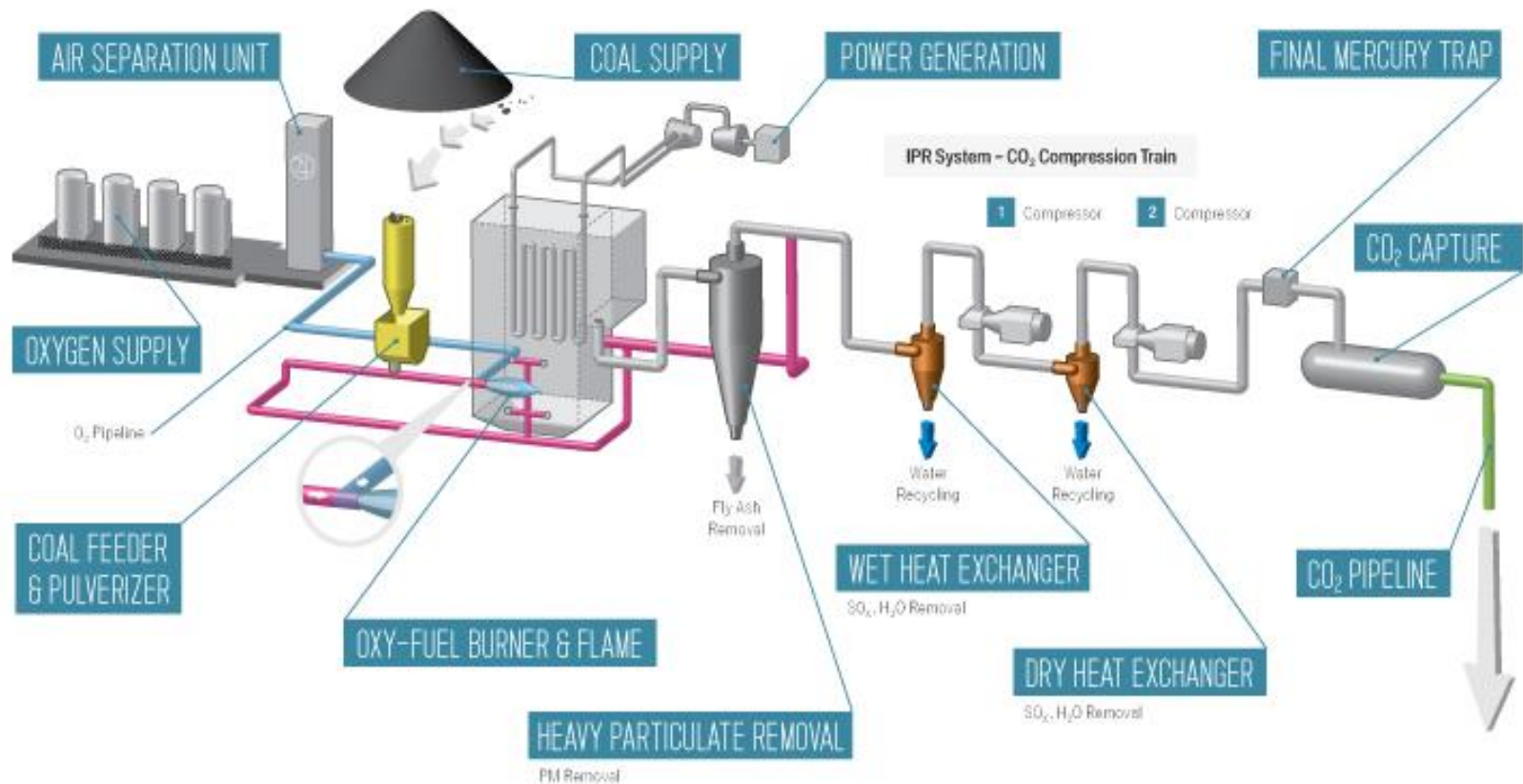


Project Objectives

- Design and construct an air-coal combustion burner for the 5 MWe equivalent test boiler. Operate air-coal burner to develop an air-coal combustion base line for the test boiler.
- Design, build, and operate a multi-radiant zone boiler system utilizing JOC high flame temperature technology
- Develop and implement a high flame temperature closed loop control strategy for the 5 MWe equivalent test boiler.

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Flue Gas Recirculation

Latent Heat Recovery

O₂ Pipeline

Water Recycling

CO₂ Pipeline

CO₂ Underground Storage and Use

- Specific Geological Formation
- Enhanced Oil/Natural Gas Recovery



Technology Background

JOC High Flame Temperature Oxy-Combustion

- Development of oxy-combustion technology for Jupiter Aluminum facility in Hammond, IN
 - Oxy-combustion process in use since 1997 in the aluminum furnace
- Jupiter Oxygen as a CRADA partner with the NETL (2003)
 - Successful retrofit of 0.5MWe equivalent boiler with JOC high flame temperature oxy-combustion
 - Produced saturated steam while maintaining boiler interior temperature profile the same as with air firing
 - Boiler efficiency gains resulted
- Jupiter Oxygen/NETL project funded by DOE (2006)



Technology Background

JOC High Flame Temperature Oxy-combustion

- Key characteristics
 - Eliminate air from the combustion system
 - Fuel and oxygen mixed at the burner undiluted with flue gas recycle except to motivate coal (unlike low temperature oxy-combustion which dilutes oxygen with flue gas recycle prior to combustion)
 - Results in a high flame temperature to enhance heat transfer in the radiant zone
 - Flue gas produced is primarily carbon dioxide and water
 - Flue gas recycle introduced around the flame/combustion zone to adjust the total flue gas volume flow and transfer heat duty to the convective zone as required
 - Additional FGR does not lower flame temperature



Technology Background

JOC High Flame Temperature

- **Benefits**
 - Significantly reduce NO_x emissions at combustion
 - Enhanced radiant heat transfer increases boiler efficiency which results in boiler fuel savings
 - Less fuel results in lower carbon generation, reduced capture costs, and lower oxygen demand
 - Reduced volume of flue gas and concentrated carbon dioxide in flue gas also reduces the cost of carbon capture
- **Challenges**
 - Burner stability and performance
 - Balancing heat duty in radiant and convective zones for retrofit projects or conventional new build projects
 - Minimizing air in-leakage to boiler



Technology Background

NETL Integrated Pollutant Removal (IPR®) System

- Key Characteristics
 - A series of compression stages where cooling upstream of each stage is leveraged for heat recovery and CO₂ purification
 - Heat recovery step employs both direct-contact and indirect heat exchange
 - Condensed water is removed from the flue gas and recycled for power plant use
 - Water-soluble materials are removed from the flue gas
- Advantages
 - Integration of IPR® with the power plant thermal cycle minimizes parasitic load for the work required to remove pollutants and capture/process CO₂
 - Condensed water captured from the combustion flue gas is sufficient offset 100% of the boiler feed water makeup and up to 7% of the cooling water makeup for the plant
 - IPR® uses “off the shelf” technology
- Challenges
 - Optimizing material selection costs while minimizing corrosion concerns
 - Treatment of captured water for release and/or use in the plant water supply



Project Accomplishments

- Retrofitted and operated a 5 MWe equivalent test boiler facility
 - No major boiler modifications required
 - No increased fouling and slagging indicated (study continues)
 - No damage to boiler materials indicated (study continues)
 - Operated the test facility with air-natural gas and oxy-natural gas combustion
 - Performed parametric studies with natural gas combustion
 - Designed, constructed, and operated a pulverized coal feed system with a scaled up oxy-coal burner from the CRADA work
 - Performed a series of oxy-coal burner development tests which resulted in a modified first generation burner
 - Performed parametric studies with the modified first generation oxy-coal burner
 - Developed a CFD model of the modified first generation burner
 - Based on test results and CFD modeling, a second generation burner has been developed, modeled, and is currently being tested



Project Accomplishments

- Designed, constructed, and operated a 20 KWe equivalent IPR[®] facility
 - Test IPR[®] system has yielded gas composition and liquid composition process results
 - Demonstrated CO₂ capture at 95% to 100%
 - Pollutant removal from captured CO₂
 - 95% NO_x , SO_x, particulate
 - 60% to 90% mercury
 - Water treatment tests (on flue gas condensate) point to FeCl₃ as an effective flocculent especially when paired with polymeric flocculent
 - In-situ corrosion sensors have been installed to characterize material possibilities in-service
- Flame analysis instrumentation upgraded to include
 - In-furnace camera viewing the entire flame
 - Mono-chromators and spectrometers detecting gray-body and radiant-gas signatures for independent temperature determination
 - Total-radiometers coupled with cameras to track total radiation while taking port-occlusion-caused attenuation into account.



Project Accomplishments

- **Air-coal baseline burner**
 - An air/coal burner has been specifically design and fabricated for the Jupiter Test Facility boiler.
 - Auxiliary equipment for the air burner system has been purchased.
- **Modular boiler system**
 - Process design has been completed
 - Equipment bid specifications have been completed and quotes received for non-fired vessels
 - Fired vessels are currently in mechanical design to develop bid drawings
- **System economic study**
 - Full-scale parametric model of a power plant retrofitted with high temperature oxy-combustion and an IPR[®] system has been developed.
 - Provided retrofit design basis to NETL systems group.
 - NETL systems group is currently developing a cost estimate for high flame temperature oxy-combustion retrofit to a commercial power plant.

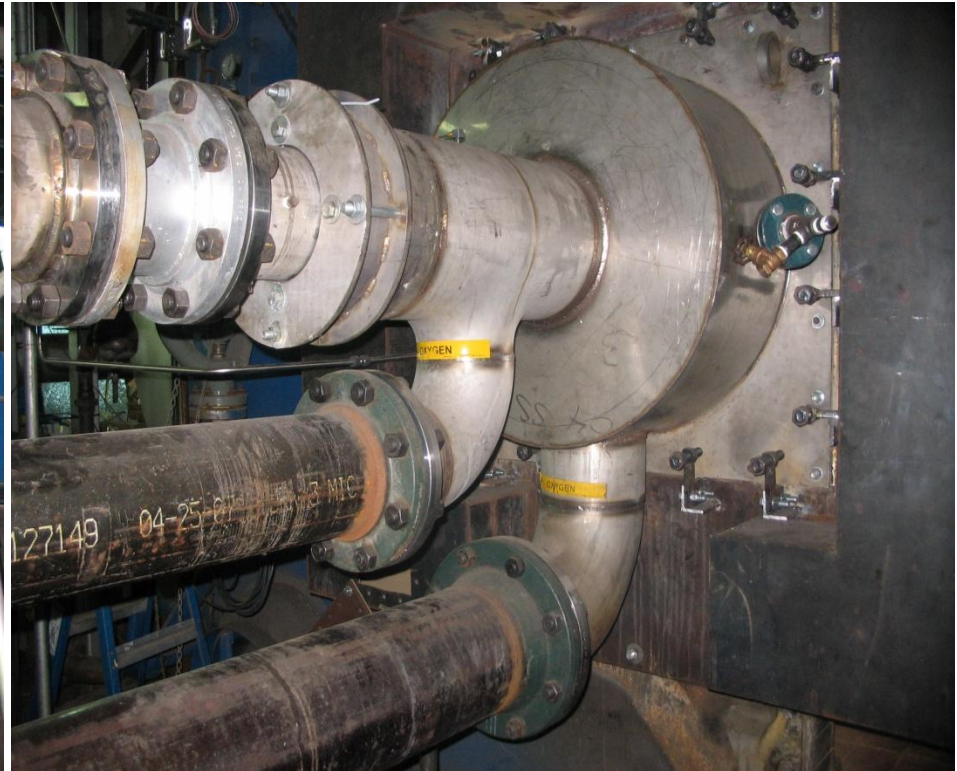


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5 MWe Equivalent Test Boiler



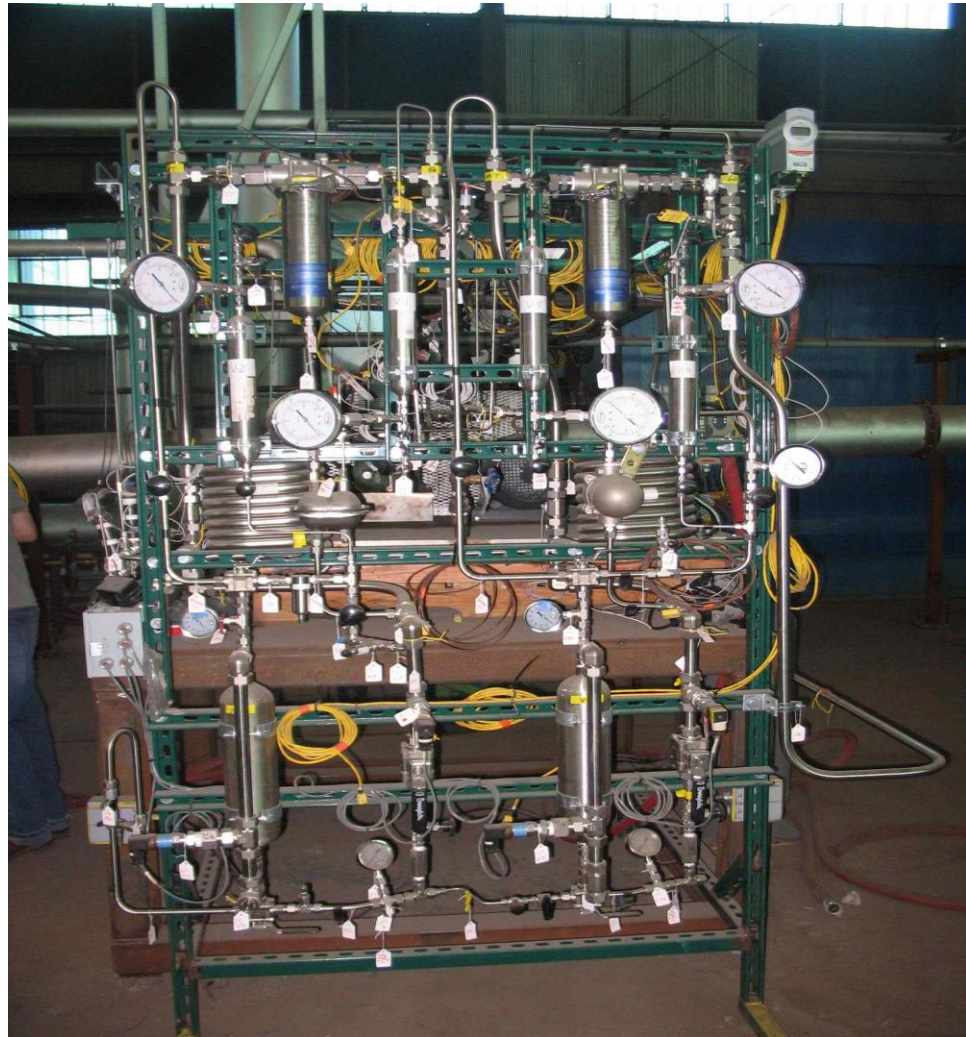
50 MMBTU/hr OXY-COAL BURNER





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20 KWe
equivalent
IPR System





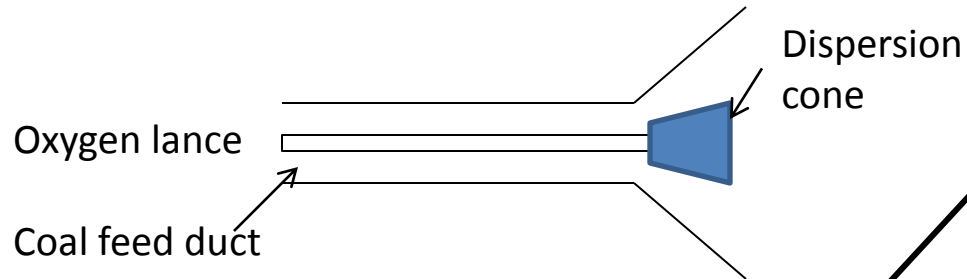
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Coal Pulverizer and Flue Gas Recycle Loop



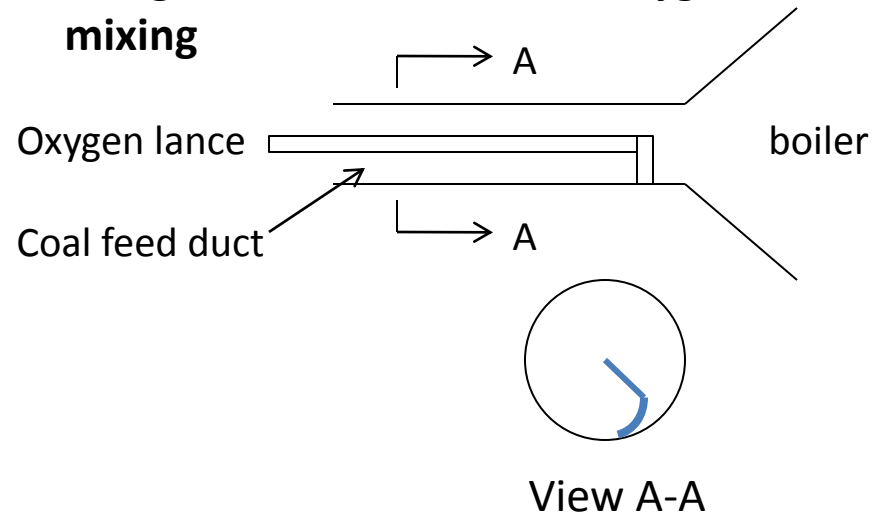


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**Modified first generation
burner arrangement**

**Oxygen swirl lance arrangement
Designed for better coal-oxygen
mixing**

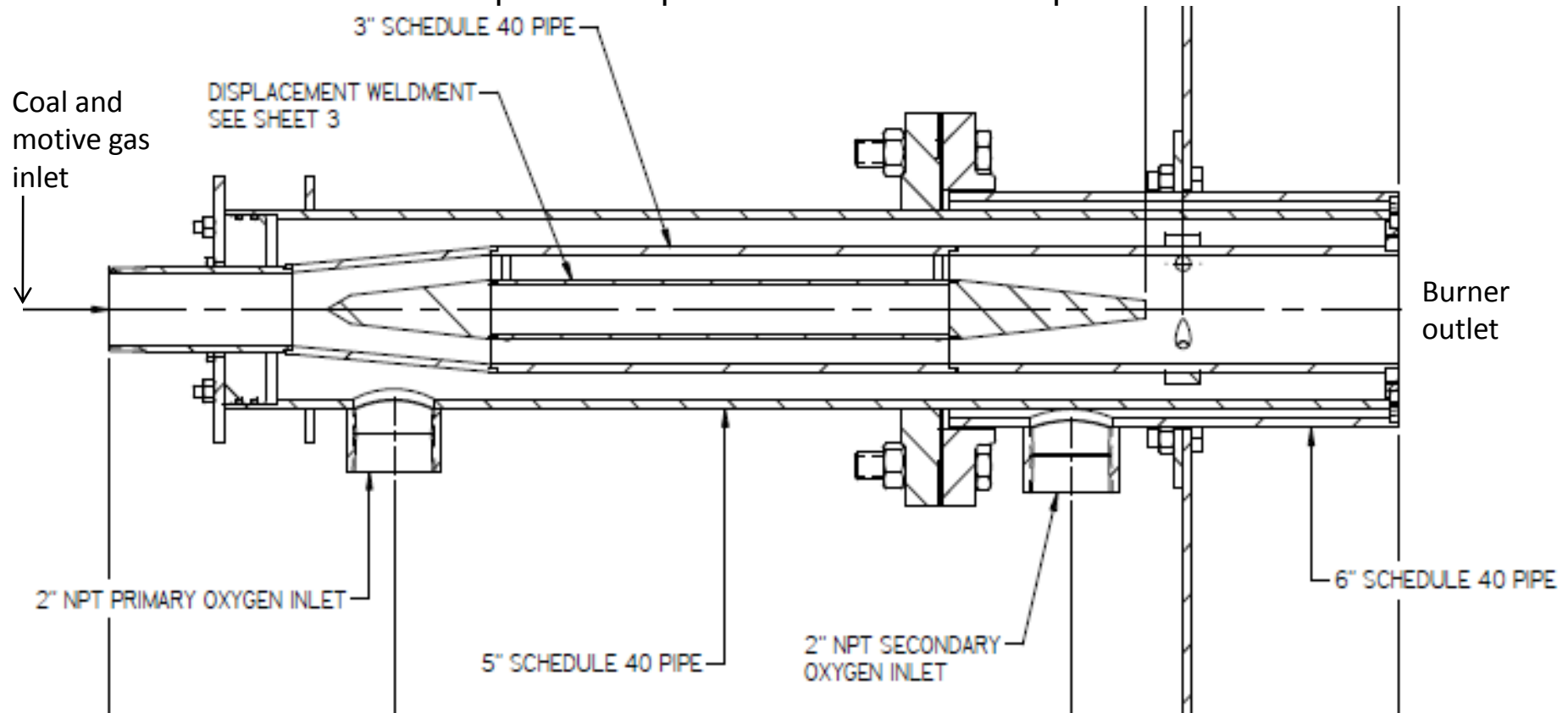




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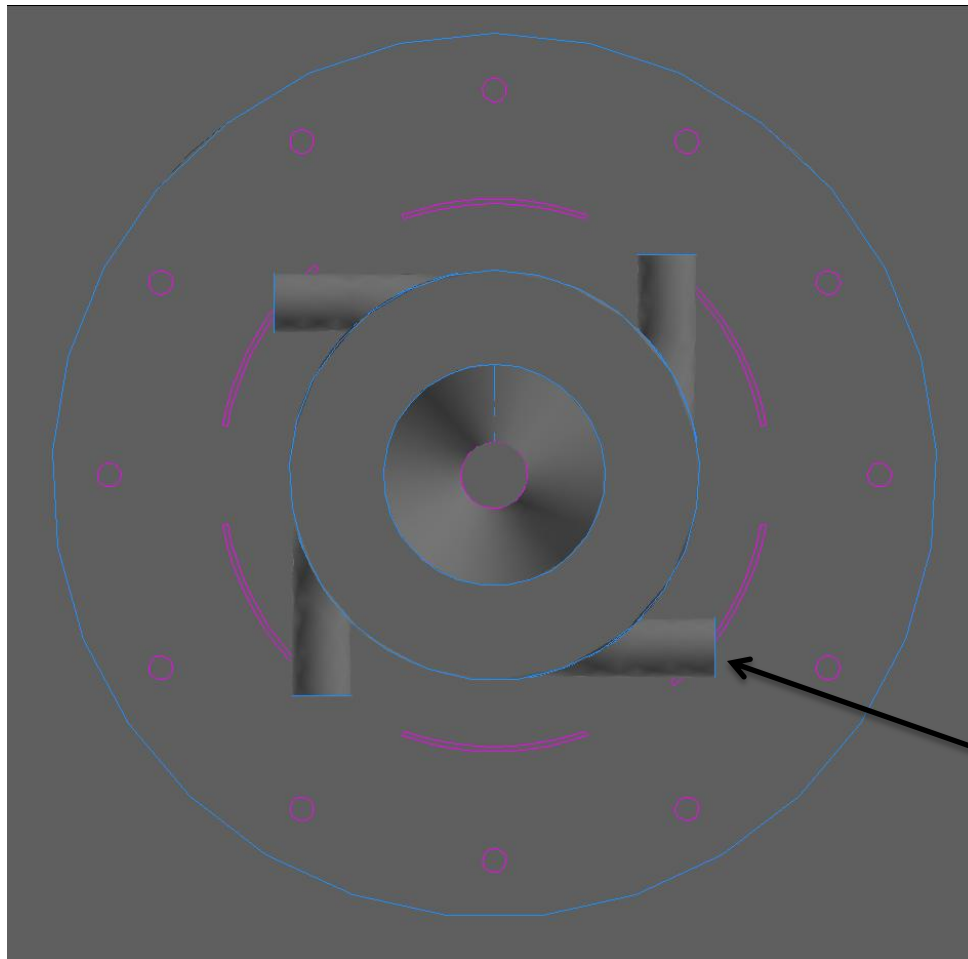
2nd Generation High Temperature OXY-coal Burner (bench scale model)

Developed in cooperation with Maxon Corporation





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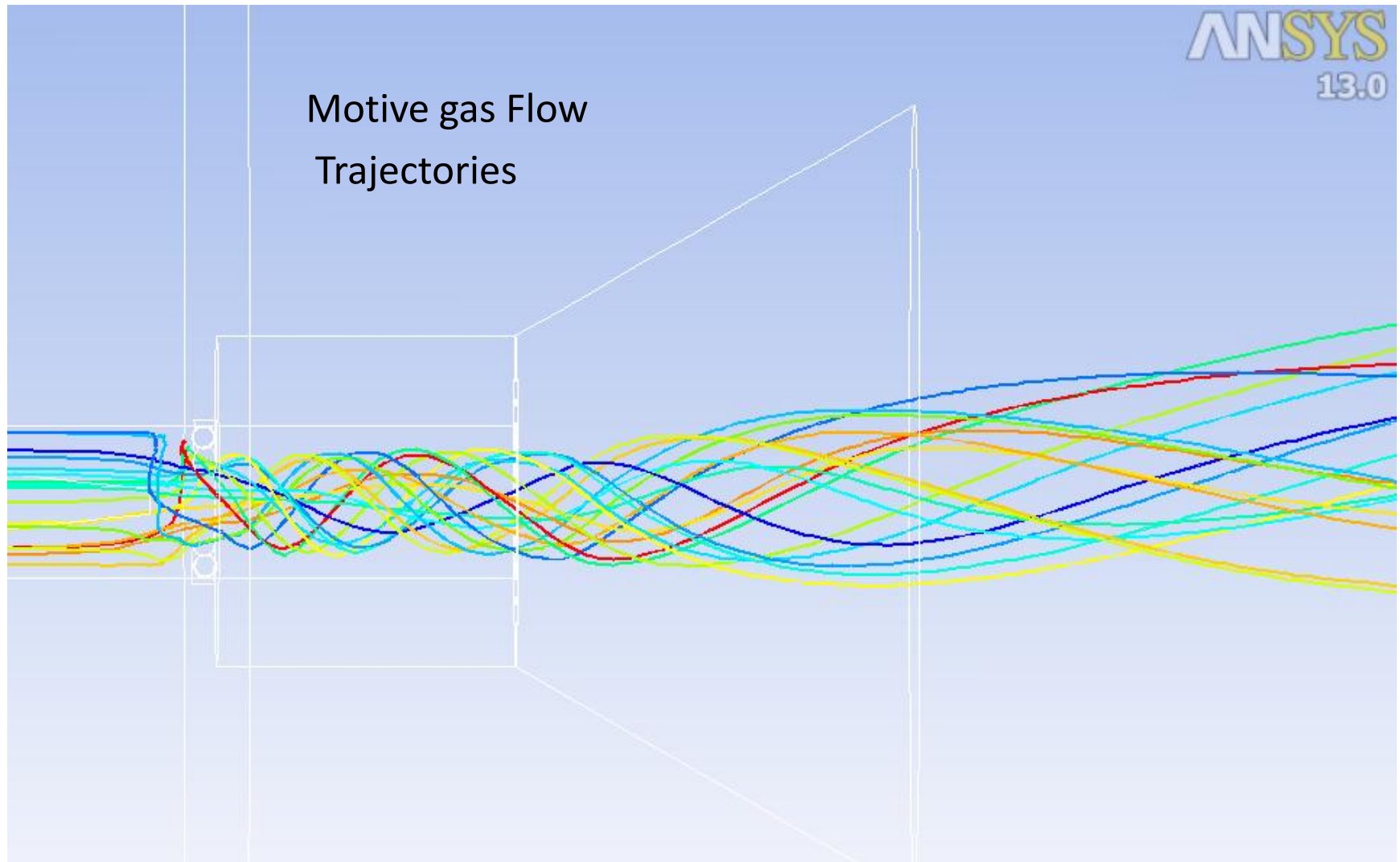
2nd Generation OXY-coal
Burner (bench scale
model – end view)

Developed in cooperation with
Maxon Corporation

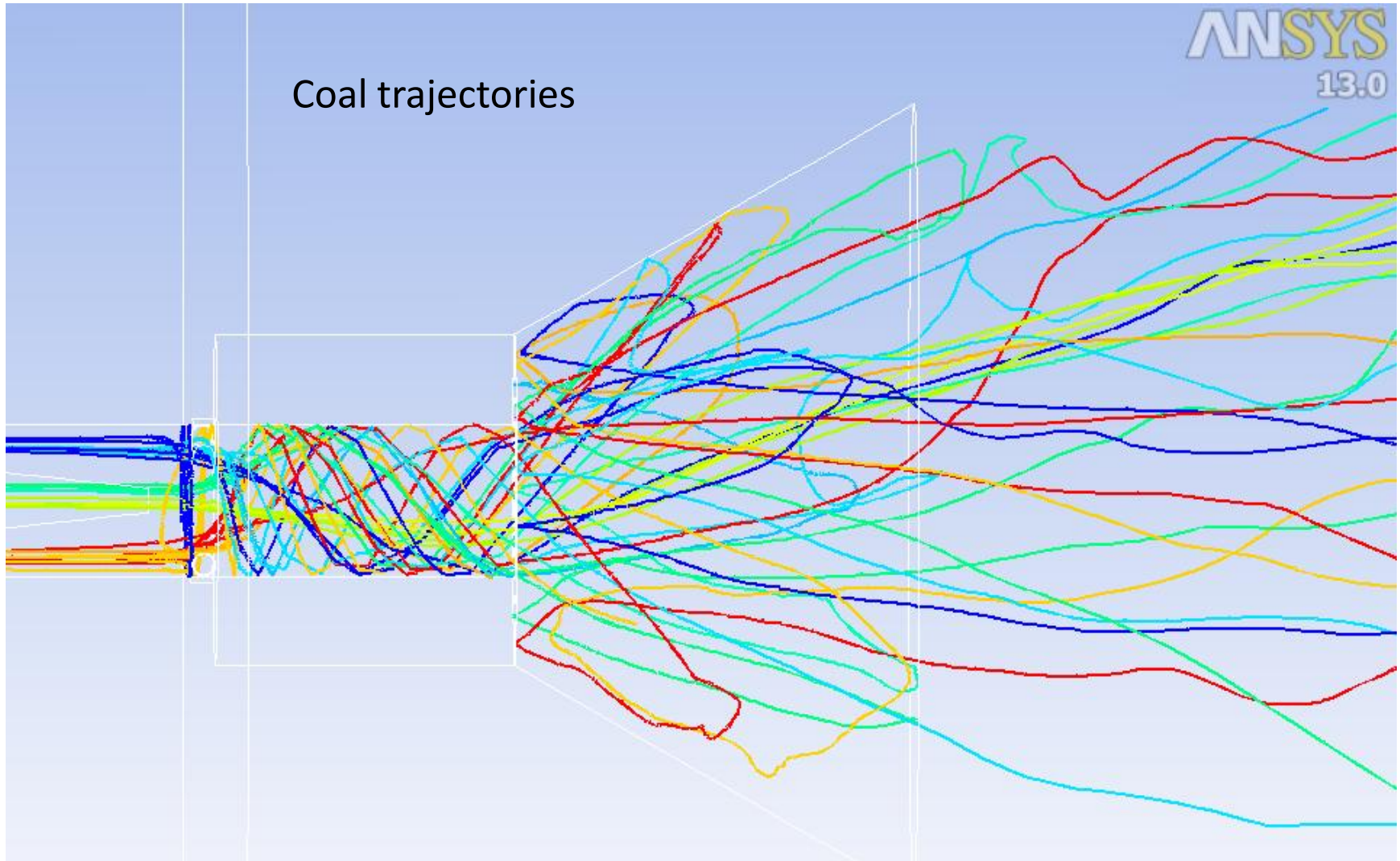
CFD modeling by NETL

Primary oxygen
Tangential ports (4)

2nd Generation OXY-coal Burner (3.4MMBTU/hr bench scale model)

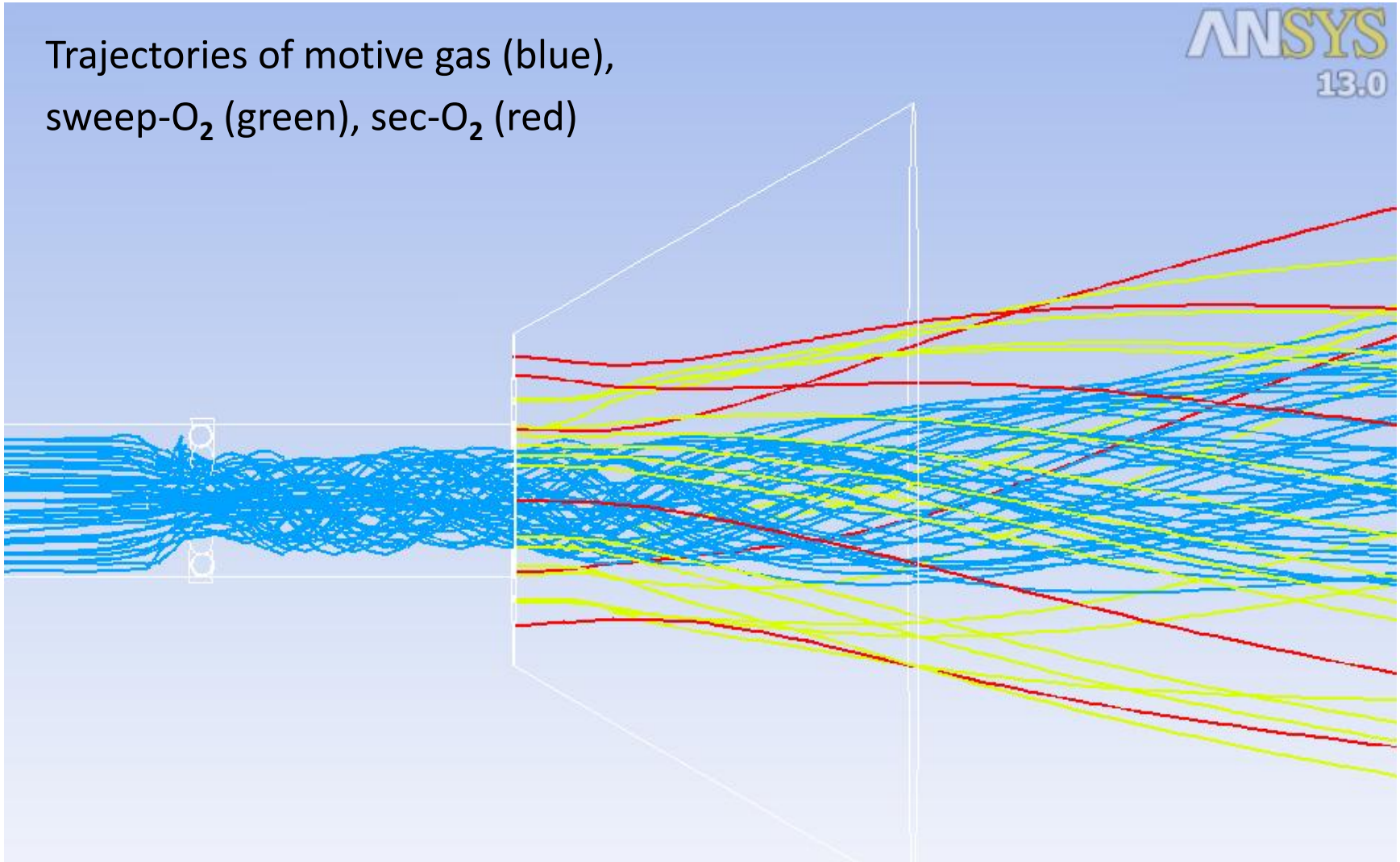


2nd Generation OXY-coal Burner (3.4MMBTU/hr bench scale model)

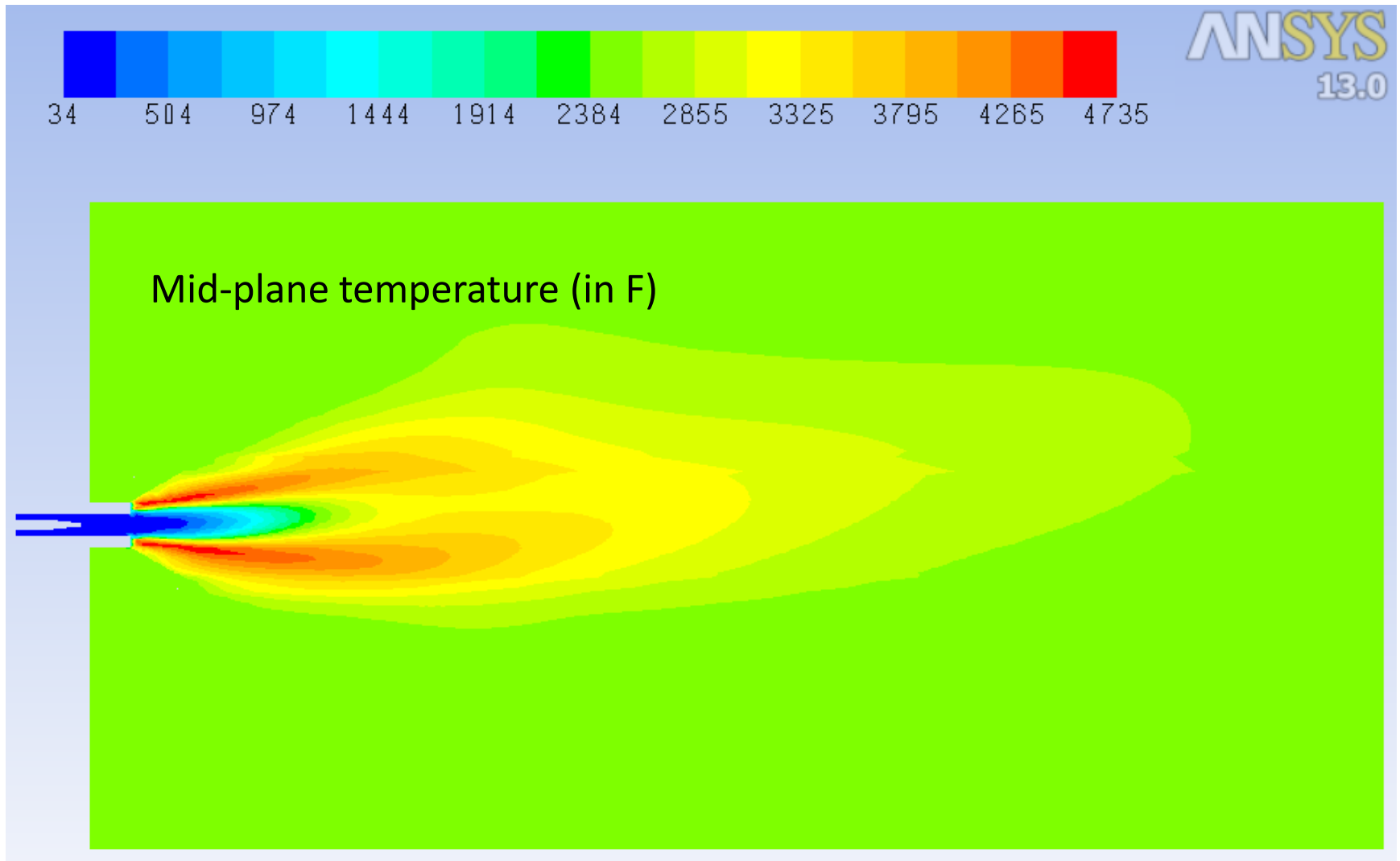


2nd Generation OXY-coal Burner (3.4MMBTU/hr bench scale model)

Trajectories of motive gas (blue),
sweep-O₂ (green), sec-O₂ (red)

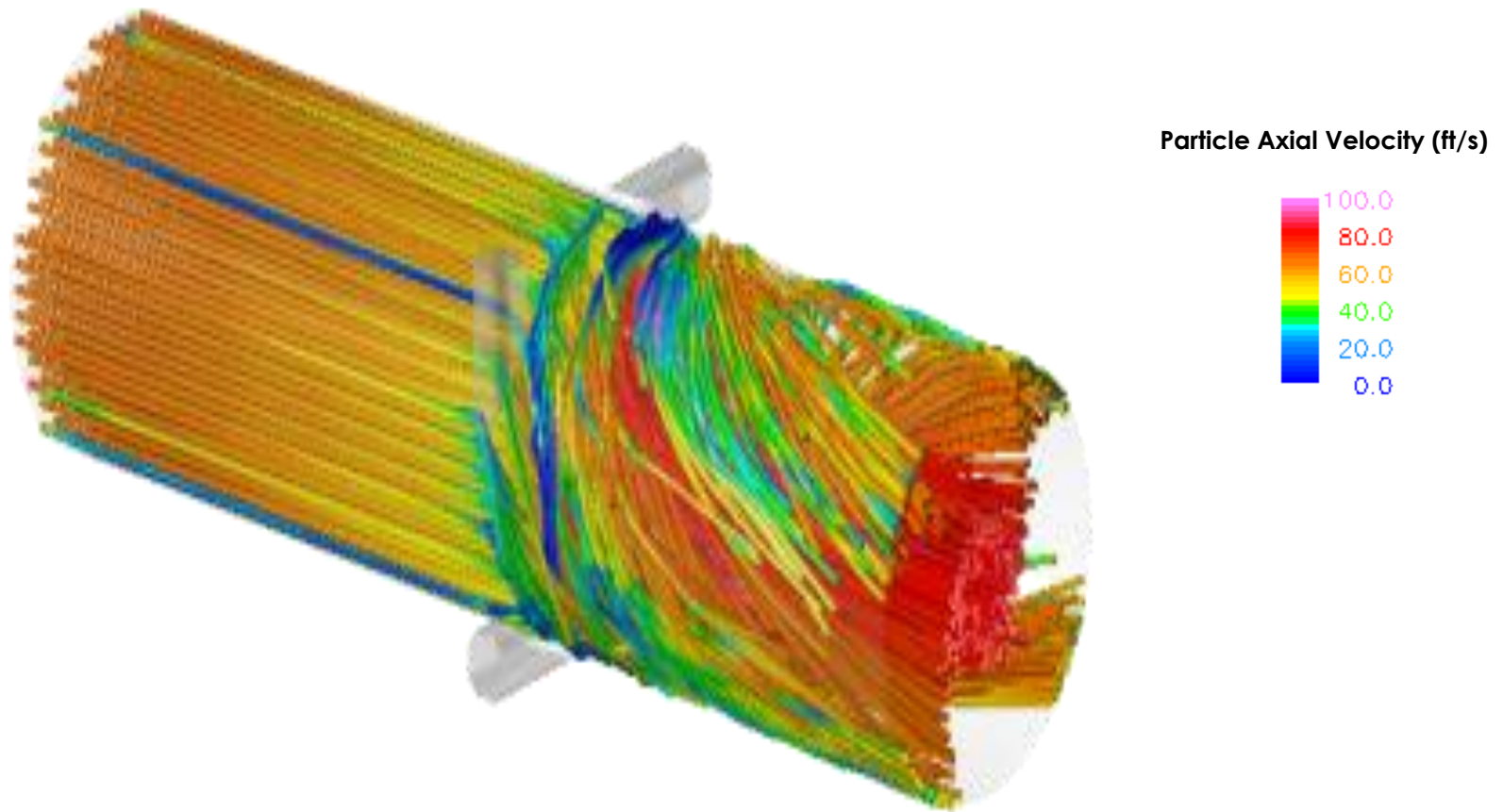


2nd Generation OXY-coal Burner (3.4MMBTU/hr bench scale model)



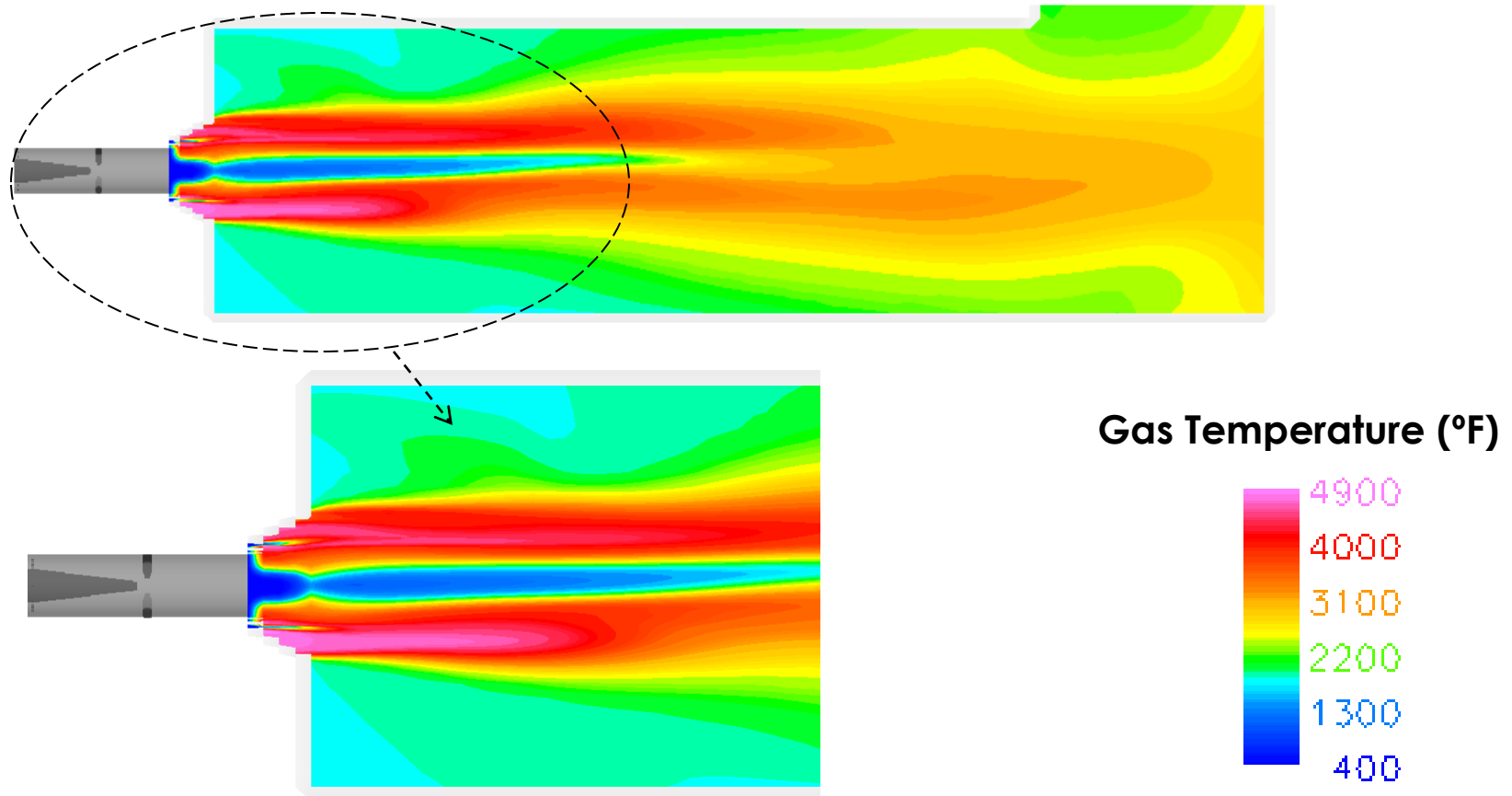
2nd Generation OXY-coal Burner (50MMBTU/Hr model)

Particle Trajectories



2nd Generation OXY-coal Burner (50MMBTU/Hr model) Gas Temperature Profiles

Radiant pass of the Hammond Test Boiler



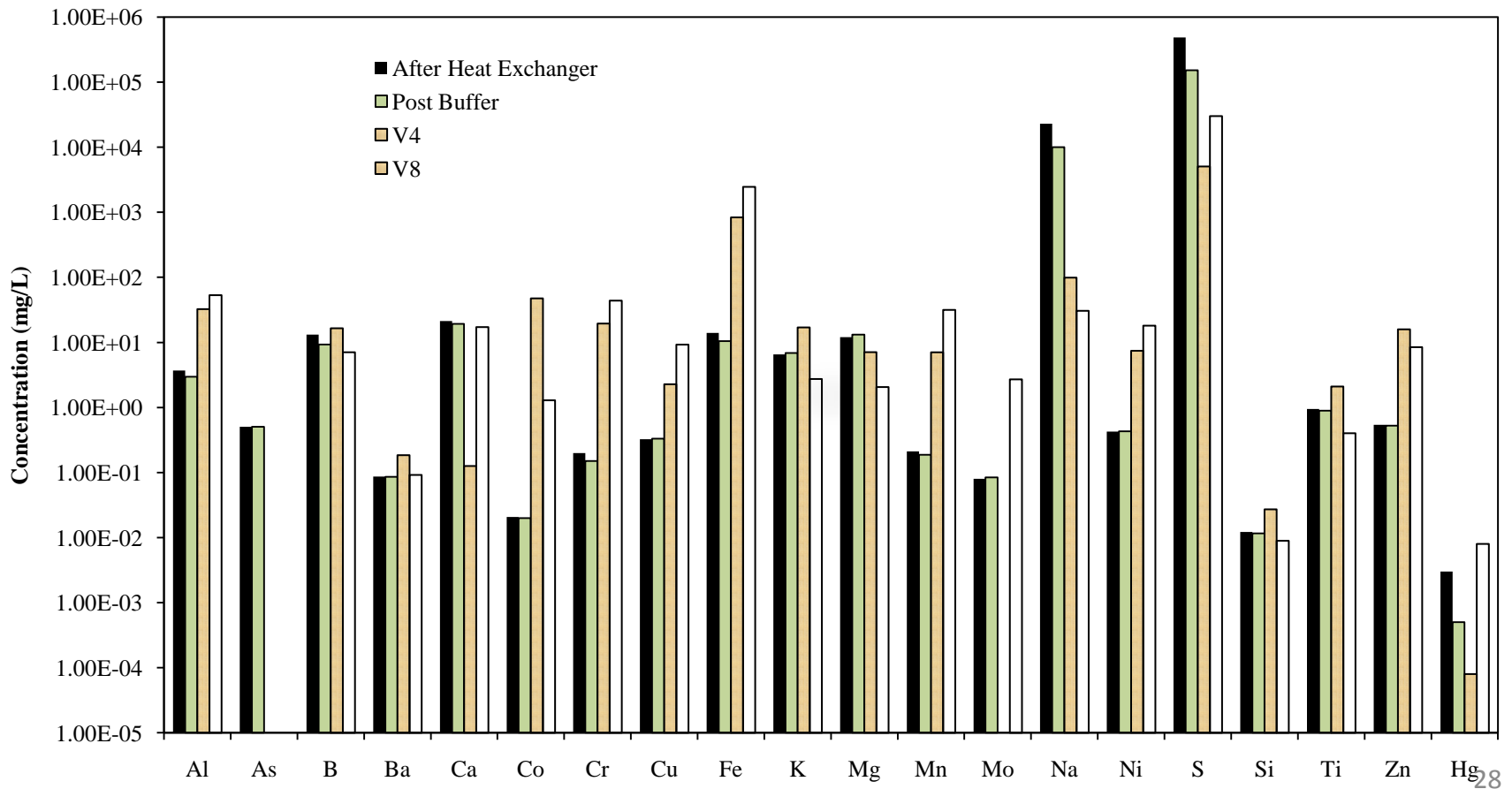
(installed at Jupiter Oxygen Burner Testing Facility, Hammond, IN)





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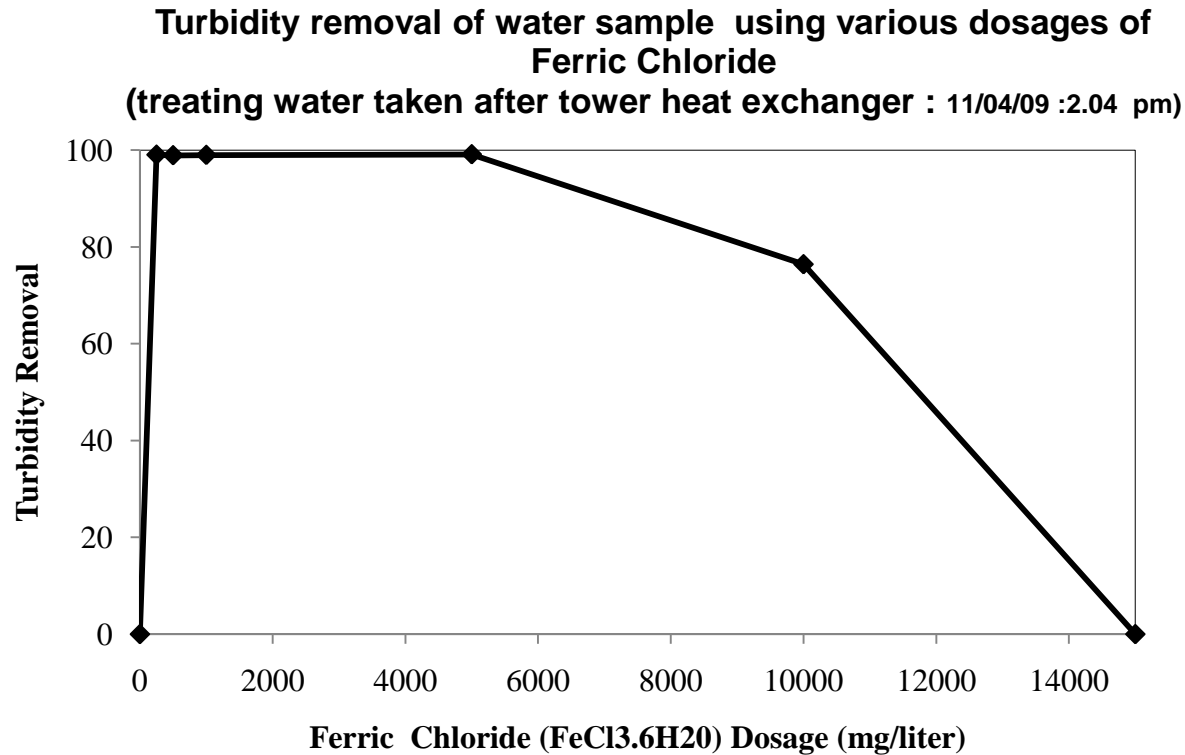
Material Dissolved in Water Sampled from IPR Cooling Stages





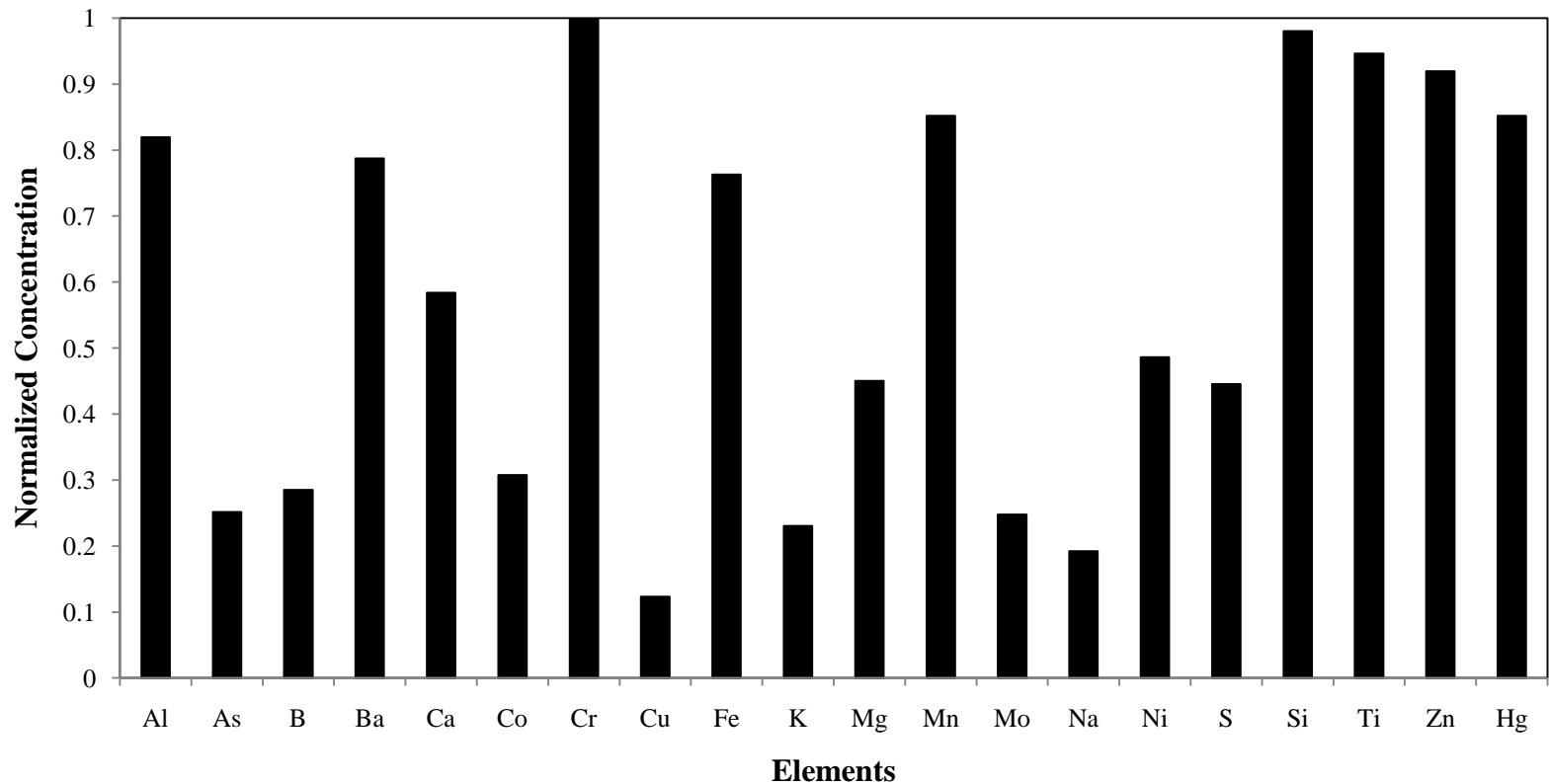
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Flocculation/Coagulation tests show ferric chloride treatment as a promising first step to purifying recovered flue-gas water (effective at low dosage)





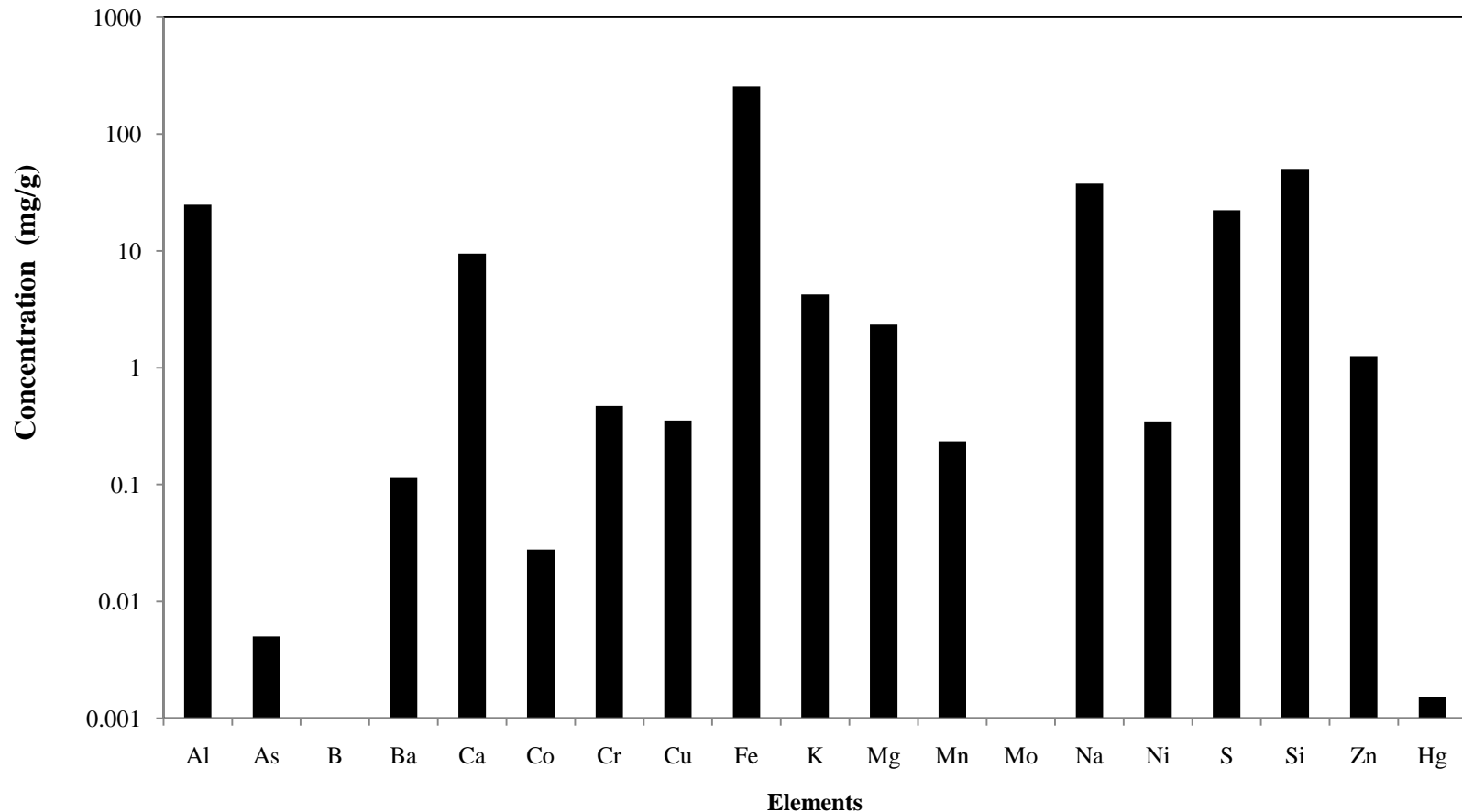
Fraction Removed by Flocculation/Coagulation





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Sludge from Flocculation Experiments





Project work going forward

- Second generation oxy-coal burner testing
 - Burner testing and comparison against CFD modeling
 - Conduct test matrix of control variables
 - Perform extended steady state run at optimal operating conditions
- Doosan Babcock slagging and fouling study
 - Modeling work already completed
 - Slag samples collected from December 2009 testing
 - Slagging and fouling study to be completed
- Develop air-coal combustion base line
 - Install purchased air-coal combustion burner assembly
 - Commission and operate to determine a base line performance for coal combustion in the JOC test boiler
 - Evaluate performance with respect to oxy-coal performance



Project work going forward

- Modular boiler
 - Complete the mechanical design of the modular boiler system
 - Develop detailed construction cost estimate
 - Construct, operate, and test the modular boiler system
- IPR[®] evaluation
 - Improved gas analysis at all stages
 - Energy recovery optimization modeling
 - In-situ and correlative lab tests for corrosion in IPR-produced environments
- Generate additional technical data for the following
 - High flame temperature oxy-coal/ IPR[®] retrofits
 - Captured CO₂ meeting EOR/sequestration specifications
 - Commercial scale-up study with economics
 - Meeting DOE Existing Plants Program Goals



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Summary

Combined Jupiter Oxygen high flame temperature oxy-combustion technology and NETL IPR[®] pollution control and carbon capture system for coal fired power plants

- Technologies provide a means to retrofit existing power plants and build new ones.
- Boiler system fuel savings can be expected from high flame temperature oxy-combustion technology.
- 95-100% carbon capture is feasible.
- Technologies allow fully carbon capture ready power plants to exist today which can be completely compliant with clean air regulatory requirements.
- Water recovery will exceed boiler feed water makeup requirements and partial cooling water makeup requirements.
- Heat integration from cryogenic oxygen plant and IPR[®] compressors can lower fuel costs.



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Summary

- While high flame temperature oxy-combustion burner and IPR[®] scale-up and optimization will continue during the current project year, these technologies are ready for commencement of a demonstration pilot project.
- The 5 MWe equivalent boiler retrofit completed for this JOC-NETL project has demonstrated
 - High flame temperature oxy-combustion can make steam in a conventional, older boiler without changing boiler interior materials
 - The IPR system uses commercialized equipment, and scale-up also will use commercialized equipment.
- Total parasitic power requirements for both oxygen production and carbon capture currently are in the range of 20%.
- Preliminary economic projections indicate that new and retrofitted coal fired power plants can achieve 95-100% carbon capture with COE increase of not more than 35% provided a net CO₂ revenue of approximately \$20 per ton.